

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

**TITLE:       SYSTEM AND METHOD FOR ECONOMICALLY VIABLE  
              AND ENVIRONMENTALLY FRIENDLY CENTRAL  
              PROCESSING OF HOME LAUNDRY**

**Field of the Invention**

The present invention relates to a process for central processing of home laundry that improves efficiency and reduces environmental impact by recycling water and chemicals.

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**Background of the Invention**

The United States is increasingly burdened with higher potable water demands and more costly downstream water treatment processes. As a practical matter, the costs for water treatment and supply are ultimately borne by the consumer. Reductions in these costs, where economically feasible, draw strong political and commercial support.

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Military, industrial, and residential sources generate voluminous quantities of "gray water" from dishwashers, wash vessels, sinks, showers, and bathtubs. These devices generate gray water and typically lack any form of recycling system. A large number of states have adopted codes for reuse of gray water. Therefore, the impetus for developing robust and economical separation strategies is a reality. The Department of Energy ("DoE") is pushing the private sector to develop more efficient, lower-water usage washing machines with minimal byproducts that are capable of using cold water.

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**Summary of the Invention**

The present invention provides a system and method using the system whereby successive loads of laundry may be washed while continuously providing effective soil removal comprising at least partially recycled wash water from at least one previous wash cycle. The system works well in laundering a wide range of stains

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and soils, such as those that are encountered in home laundry. The system and the method of using the same comprise filtering wash water with at least one filter to form wash retentate and wash permeate. The use of wash permeate in successive washes provides for reuse of chemicals and water recovery. A similar arrangement  
5 may be used with regard to the rinse water. Advantageously, one embodiment of the invention provides for the use of rinse retentate as make up water in the wash loop that increases water recovery and chemical recovery. The use of additional loops may provide greater recovery. Ultimately, the invention can reduce the production of gray water, reduce the discharge of potentially harmful detergent ingredients into the  
10 environment, and recover chemicals used in the laundering process.

### **Brief Description of the Drawings**

FIG. 1 is a process flow diagram of one embodiment of the present invention;

FIG. 2 is a process flow diagram of another embodiment of the present  
15 invention;

FIG. 3 is a process flow diagram of another embodiment of the present invention;

FIG. 4 is a process flow diagram of another embodiment of the present invention;

FIG. 5 is a graph of the surface tension vs. detergent concentration for Tide™  
20 powder detergent;

FIG. 6 is a graph of the permeate flux as a function of feed/retentate volume for a variety of combinations;

FIG. 7 is a graph of the soil removal of red wine after subsequent washes  
25 under a variety of conditions;

FIG. 8 is a graph of the soil removal of raw, unbleached after subsequent washes under a variety of conditions;

FIG. 9 is a graph of the soil removal of Immedial Black after subsequent washes under a variety of conditions;

FIG. 10 is a graph of the soil removal of blood, milk, and carbon black after  
30 subsequent washes under a variety of conditions;

FIG. 11 is a graph of the soil removal of cocoa after subsequent washes under a variety of conditions;

FIG. 12 is a graph of the soil removal of blood after subsequent washes under a variety of conditions;

5        FIG. 13 is a graph of the soil removal of carbon black and olive oil after subsequent washes under a variety of conditions;

FIG. 14 is a graph of the soil removal of blood, milk, and carbon black after subsequent washes under a variety of conditions;

10       FIG. 15 is a graph of the soil removal of Dust Sebum from cotton after subsequent washes under a variety of conditions;

FIG. 16 is a graph of the soil removal of Dust Sebum from polyester after subsequent washes under a variety of conditions;

FIG. 17 is a chart showing the reflectance of redeposition swatches from Set 1;

FIG. 18 is a chart showing the reflectance of redeposition swatches from Set 2;

15       FIG. 19 is a chart showing the reflectance of redeposition swatches from Set 3;

FIG. 20 is a chart showing the reflectance of redeposition swatches from Set 4;

FIG. 21 is a chart of the reflectance of redeposition swatches dried without a fabric softener from Set 5;

20       FIG. 22 is a chart of the reflectance of redeposition swatches dried without a fabric softener from Set 4;

FIG. 23 is a graph reflecting the active matter analysis of water from subsequent washes for Set 1;

FIG. 24 is a graph reflecting the active matter analysis of water from subsequent washes for Set 2;

25       FIG. 25 is a graph reflecting the active matter analysis of water from subsequent washes for Set 3;

FIG. 26 is a graph reflecting the active matter analysis of water from subsequent washes for Set 4;

30       FIG. 27 is a graph reflecting the total organic carbon analysis of water from subsequent washes for Set 1;

FIG. 28 is a graph reflecting the total organic carbon analysis of water from subsequent washes for Set 3;

FIG. 29 is a graph reflecting the total organic carbon analysis of water from subsequent washes for Sets 4;

5 FIG. 30 is a graph reflecting the total organic carbon analysis of water from subsequent washes for Sets 5;

FIG. 31 is a graph reflecting the soil removal on test strips;

FIG. 32 is a chart reflecting the reflectance of redeposition swatches dried with fabric softener sheets; and

10 FIG. 33 is a chart reflecting the reflectance of redeposition swatches dried without fabric softener sheets.

### **Detailed Description of the Invention**

The present invention provides an economically viable process for central and substantially continuous processing of home laundry in an industrial laundering system. The process preferably achieves effective soil removal and efficient water and surfactant recovery and recycling. As used herein, detergency is relative to an initial wash in a series where fresh water is used.

15 In one embodiment, the percent removal or "detergency" may be calculated as follows:

$$\% \text{ Removal} = \{[(R_w - R_s)/(R_0 - R_s)]\} (100)$$

$R_w$  = reflectance of the washed swatches

$R_s$  = reflectance of the soiled swatches

$R_0$  = reflectance of the blank swatches

25 (scoured fabric)

$$R_i = 100 - ((100 - L_i)^2 + a_i^2 + b_i^2)^{1/2}$$

"L" = reflectance on black/white scale

"a" = reflectance on red/green scale

"b" = reflectance on yellow/blue scale

30 Furthermore, effective soil removal preferably retains the color-fastness of the fabric cleaned.

In addition to achieving effective soil removal, the present invention provides for efficient recovery of water and surfactants. Overall water recovery is least about 60%, preferably at least about 70%, and more preferably at least about 80%, and most preferably about 90% or more. Overall surfactant recovery is at least about 10%,  
5 preferably about 20% or more, and more preferably about 30% or more.

Numerous aspects of the invention may be varied without departing from the scope of the invention. The following parameters may be varied, depending on the situation and the specific parameters desired. With regard to each parameter, a preferred parameter or range has been shown, but those skilled in the art should  
10 recognize that these parameters are not definitive, but illustrative of the benefits of a preferred embodiment of the invention.

For example, the filter size affects the size of contaminants and detergent ingredients that are returned to washer in water. The filter size may have the following effects: about one micron filters remove hair, pollen, and sand; about 0.1  
15 micron filters remove most bacteria and dust; about 0.01 micron filters removes viruses and carbon black; and about 0.001 micron filters remove synthetic dye and surfactants. Though smaller pore sizes reduce water flux during filtration, those skilled in the art will recognize the benefits of selecting a certain filter depending on which contaminants and detergent ingredients that are desired to be returned to the  
20 wash vessel in the water. Though a preferred range of filters is about .005 to about 5 microns, a more preferred filter size is about .01 to about 0.2 microns allows the removal of dirt, viruses, and bacteria without removing most surfactant or similar cleaning agent and also allows reasonable water flux.

Furthermore, the filter material affects the rate of water flux and surfactant  
25 flux and provides the chemical and physical resistance of the filter. Fluoropolymers such as polytetrafluorethylene or Teflon® materials are hydrophobic but are resistant to temperature and chemicals like bleach. Polyacrylonitrile is hydrophilic, allows good water flux as a result, but is less resistant to high temperature and corrosive chemicals. Filter materials may also include ceramics, polyethylene terephthalate,  
30 polyvinylidene fluoride, cellulose, cellulose acetate, and polypropylene. In a preferred embodiment, the filter may contain polyacrylonitrile because it provides

good water and surfactant recovery and has reasonably good chemical resistance at conditions utilized in this process.

Moreover, the type of filter determines rate of water flux and fouling while determining mechanical action occurring at the surface of the membrane. Types of filters that are effective include filters capable of crossflow filtration or vibratory-enhanced filtration. Both of these types provide good water flux with minimal fouling with typical soil loading in the washwater.

The wash vessel or washing machine type affects the mode of cleaning and the size of laundry load allowed in the system. Wash vessels or washing machines that may incorporated into the system include but are not limited to household top-load machines, household front-load machines, and industrial front-load machines. The incorporation of at least one industrial front-load washing machine is preferable because each machine may be capable of segregating wash and rinse water and/or automatically dosing detergent while providing the best option for large-scale processing of laundry.

Detergent type determines cleaning profile achieved in laundry process. Notably, the detergent may be a powder or a liquid. Preferably, the detergent comprises: surfactants such as anionic, nonionic, cationic, phosphates, and/or amphoteric surfactants capable of providing cleaning and foaming; builders such as sodium carbonate, zeolite, and/or soda ash capable of minimizing the effects of water hardness and minimizing soil redeposition; hydrotropes capable of increasing solubility of ingredients in liquid formulations; fluorescent whitening agents to whiten fabrics; enzymes to help the surfactants clean tough stains and soils; polymers such as polyvinyl pyrrolidone, carboxymethylcellulose, or polyacrylate capable of preventing soil redeposition and dye transfer; perfumes capable of adding fragrance to clothing; bleach containing chlorine or peroxygen compounds capable of whitening fabric; and/or a defoamer such as soap or silicon oil. Preferably, all of these ingredients can be used in the wash recycle. Chlorine bleach should be added separately in the wash cycle from the rest of the ingredients for optimal performance. In a most preferred embodiment, the use of liquid detergent with no zeolite (because zeolite may clog the filter and is not necessary in soft water), chlorine bleach used in last part of wash

cycle, and nonionic surfactants and silicone defoamers that provide the preferred low foaming in soft water are used. Although substantially any laundry detergent may be used in the process of the invention, liquid laundry detergents are preferred. A most preferred liquid laundry detergent is liquid Procter & Gamble's Tide High Efficiency™ detergent known is Tide HE™ detergent. Additional detergents such as Unilever's Wisk™ are envisioned to be within the scope of the invention. Those skilled in the art will recognize that virtually any detergent comprising at least one surfactant may benefit from the present invention.

As discussed herein, the water quality is also a factor. Soft or hard water affects the level of cleaning and foaming. Though the present invention may use soft or hard water, soft water is preferred for cleaning and rinsing. In the event that soft water is used, a defoamer may be needed to prevent excessive foaming during washing and rinsing. Hard water or soft water may be used as the wash water in the invention. In a preferred embodiment, soft water is used. As used herein, the term "soft water" is defined to mean water that is substantially free of multivalent ions, including but not necessarily limited to calcium and magnesium ions. A preferred embodiment of the invention uses a combination of liquid detergent, such as liquid Tide HE™ detergent and soft water. When this combination is used, filtration performance may reach a steady state with the soils tested corresponding to good flux and a possible chemical recovery, *e.g.*, surfactant, of about 30%.

Washing temperature affects the level of cleaning and bleaching. The washing temperature may be between about 10°C and about 90°C, approximately 40°C is preferred to give good cleaning and chlorine bleaching without excessive wear on the clothes. Rinsing temperature has less impact than washing temperature. Lower temperatures mean less energy requirements. Though the rinsing temperature may be between about 10°C and about 90°C, approximately 25°C will provide good rinsing with little waste of energy. Filtration temperature affects the rate of filtration. Higher temperatures may increase water flux. Though the filtration temperature may be between about 10°C and about 90°C, approximately 30°C provides good water flux with little wear on the filter.

The water recycle ratio affects the amount of water, energy, and chemical

savings. Water may be recycled in either or both the wash and the rinse loops. Though the recycle ratio may be between about 30% and about 90%, a recycle ratio of between about 80% and about 90% with good cleaning can be achieved with effective filtration of rinse and wash water in the preferred embodiment.

5 As shown herein, the present invention may include several variations. Some of the preferred variations of the system include: filtering the wash only with fresh water used for rinse to provide good cleaning but lower water recovery; providing two isolated filtered rinse and wash loops that may allow cationic fabric softener to be used in rinse loop; providing two loops with processed rinse retentate used to make up  
10 the water in the wash loop which maximizes water and chemical recovery but usually prevents use of cationic fabric softener in rinse loop because cationic will react with anionic in wash cycle water; and providing three or more loops that allows maximum water and chemical recovery by tailoring filtration to allow maximum recovery of chemical and maximum detergent effectiveness of the process.

15 In one embodiment, the wash water and rinse water do not have to be segregated. The combined wash and rinse water may be treated, a fraction of treated water may be mixed with fresh water, and the resulting mixture may be used for the wash and the rinse steps in subsequent cycles. In this embodiment, foaming of the recycled water in the rinse step may occur that would benefit from the use of a  
20 defoamer. Alternatively, the wash water and rinse water may be segregated in order to achieve desired water reuse levels.

In a preferred process for recycling wash and rinse water, an amount of rinse effluent and wash effluent are separately collected from at least one wash vessel and maintained in a segregated fashion. Large particulate matter may be filtered from the  
25 wash effluent to produce a prefiltered wash effluent. The prefiltered wash effluent may be microfiltered to produce a wash effluent permeate and a wash effluent retentate. At least a portion of the wash effluent permeate may be recycled back to the wash vessel. Furthermore, a portion of the rinse effluent also may be circulated back to the wash vessel, preferably after a filtration to remove some particulates.

30 In a preferred embodiment, the rinse water is subjected to substantially the same treatment as the wash water. Preferably, large particulate matter can be filtered

from the rinse effluent to produce a prefiltered rinse effluent. The prefiltered rinse effluent may be microfiltered to produce a rinse effluent retentate and a rinse effluent permeate. At least a portion of the wash effluent permeate may be recycled back to the wash vessel. Finally, a portion of the rinse effluent retentate also may be added to the prefiltered wash water (preferably before microfiltration) in order to avoid the need to add fresh make-up water to the wash loop and to maximize water and surfactant recovery.

The following provides some of the preferred embodiments of the invention. Like designation numerals have been used for like elements throughout. Those skilled in the art realize that substantial deviation from these embodiments is envisioned to be within the scope of the invention.

Referring to FIG. 1, a load of laundry is placed in a wash vessel 20. A hot or wash water feed 22 provides hot or warm water into the wash vessel 20 to wash the laundry. A cold or rinse water feed 24 provides cold water into the wash vessel 20 to rinse the laundry. The hardness level of the wash water feed 22 and the rinse water feed 24 impact the efficiency of the process. Preferably, the water for both feeds is "soft water."

The temperature of the water in each feed impacts the efficiency of soil removal. The wash water will clean more effectively if it is warmed before being fed into the wash vessel. The wash water feed 22 is heated to about 40°C. Those skilled in the art will recognize that variation of the temperature is within the scope of the invention. The water may be heated using any suitable means, such as a steam coil, electrical coil, or similar method known to those skilled in the art.

After a wash cycle, the wash water effluent 26 is passed through a suitable large pore filter 28 to remove large particulate matter. Large particle matter includes visible particulate matter and matter having a relatively high molecular weight. Typically, suitable filters will not retain molecules with molecular weight below about 500,000. Examples of suitable filters include, but are not necessarily limited to, wire mesh or other sieves or large pore filters. The prefiltered wash effluent 30 is collected in a holding vessel 32 and mixed with make-up water 33, as necessary. Preferably, the make-up water 33 also is soft water.

The wash effluent stream 34 is passed to a filter 36. The filter 36 may be any suitable filter adapted to reject or remove "filtrate" comprising species with a molecular weight cut off ("MWCO") of about 5,000 or more, including, but not necessarily limited to reverse osmosis filters, nanofilters, ultrafilters, and microfilters.

5 In a preferred embodiment, the wash effluent stream 34 is passed through a microfilter known as a tubular membrane filter such as that described in U.S. Patent No. 5,868,937, which is incorporated herein by reference. A most preferred tubular membrane filter comprises a tubular membrane with an average pore diameter of about 0.1 micron. This pore size is expected to remove particulates, emulsifier oily  
10 soils, and/or insoluble builders such as zeolites.

Membrane filtration is defined as the use of polymeric or ceramic substrates in the form of spiral-wound modules or tubes designed to separate species in a liquid or gas stream according to molecular size and chemical properties. The spectrum of membrane filtration for liquids varies from reverse osmosis ("RO") to microfiltration ("MF"), between which nanofiltration ("NF") and ultrafiltration ("UF") fall. The  
15 spectrum itself is defined in terms of MWCO, which is a measure of the molecular sizes (*i.e.*, molecular weight of species) beyond which the membrane will reject. The assigned values for RO, NF, UF, and MF are nominal and also depend on the membrane. For the purposes of the following discussion, "microfiltration" will refer  
20 to molecular weight cutoffs in the range of between about 5,000 and about 500,000. For example, species such as endotoxins, pyrogens, virus, bacteria, pigments, dyes, red blood cells, emulsified oils, and other organics, asbestos, and pollen can be removed by membranes having MWCOs of nominally about 5,000 or less.

Reverse osmosis or RO will reject species on an ionic scale (molecular  
25 weights of between about 200 and about 500 and lower). Nanofiltration or NF will reject species on a molecular scale (molecular weights of between about 200 and about 10,000). Ultrafiltration or UF will reject species in the macro-molecular scale (molecular weights of between about 1,000 and about 500,000). Finally, microfiltration or MF will reject species from molecular weights of between about a  
30 100,000 and about 1,000,000 (pore size of between about 0.05 microns and about 1 micron). All four separation categories should reject bacteria—a benefit in recycle

systems where bacteria are present. The pressure (*i.e.*, power) and high-pressure plumbing (*i.e.*, system weight) requirements for membrane separation processes decrease from the about 400 lb./in<sup>2</sup> absolute ("psia") in RO systems to approximately between about 10 and about 20 lb./in<sup>2</sup> gauge ("psig") for MF systems. Aside from the  
5 system requirements, the separation results using lower MWCO membranes (*e.g.*, RO) may not always be as desirable and the membranes may be more prone to contamination and plugging problems.

The permeate of a membrane filtration system is generally defined as the fluid (gas or liquid) which permeates through the membrane structure. The retentate is the  
10 fluid that does not filter through the membrane structure and is therefore swept across, or out of, the membrane cartridge. Passage of the wash water through the filter 36 produces a wash effluent retentate 38 and a wash effluent permeate 40.

The wash effluent permeate 40 passes to a wash water holding vessel 42 and is mixed with make-up water 43, as needed. Preferably, the make-up water 43 also is  
15 soft water. The wash effluent retentate 38 is circulated back to holding tank 32 and later discarded as wastewater 44.

The rinse water 46 similarly is removed from the wash vessel 20 and fed to a rinse water holding vessel 48. Thereafter, the rinse water 50 preferably is transferred from the holding vessel 48 to a mixing vessel 52, where it is mixed with fresh make-  
up water 53. Because fabric and other particles tend to plug the screen on the washer  
inlet line 24, a bag filter 54 treats the rinse water in mixing vessel 52 before it is drawn and reintroduced into the wash vessel inlet 24.

A second embodiment, depicted in FIG. 2, is substantially the same as the first embodiment and uses like element designations for like elements, except that only  
25 one holding vessel 52 is used for the rinse water and the bag filter 54 is omitted. Because the wash loop is the same, only the rinse cycle in FIG. 2 will be described. The rinse water 46 is removed from the wash vessel 20 and fed to a rinse water holding vessel 52. Thereafter, the rinse water 24 preferably is transferred from the holding vessel 52 to a wash vessel 20. In this embodiment, the resulting mixture is  
30 reused in the rinse cycle without adding fresh make up water or passing the mixture through a bag filter.

Another embodiment is depicted in FIG. 3. In addition to many of the elements previously discussed with respect to FIG. 1, wherein similar numerical designations are used to denote similar elements, a second pore filter 29 is disposed in the rinse influent stream 46. Moreover, this embodiment benefits from a second filter 37, that may be any filter such as the ones discussed with reference to filter 36 in FIG. 1, but is preferably a microfiltration unit. The filter 37 replaces the bag filter 54 system shown in FIG. 1. By disposing the filter 37 between the rinse water holding vessel 48 and the mixing vessel 52, the filter 37 processes the rinse effluent from the rinse water holding vessel 48 leaving a waste stream 49. The rinse water stream 50 is filtered and may be mixed with fresh make up water 53 in mixing vessel 52.

Another embodiment of the present invention is shown in FIG. 4. Like numeral designations have been used to indicate like elements as previously shown in FIGs. 1-3. A portion of the rinse water retentate 60 is mixed with the wash water effluent in holding vessel 32 prior to filtration. In this embodiment, fresh water (previously shown as element 33 in FIGs. 1-3) preferably is not used as make-up water in the wash water filtration loop.

Removing particulate matter and filtering the permeates reduces the overall amount of water recovered. The loss can be overcome by adding an amount of make-up water to the rinse effluent permeate and the wash effluent permeate. The make-up water added to the wash effluent may be fresh or unrecycled water, rinse effluent (preferably at least prefiltered), rinse effluent retentate, and/or rinse effluent permeate. The rinse effluent permeate and the wash effluent permeate may be passed directly to a wash vessel for re-use, or stored in a storage vessel for future use.

The embodiments have been implemented as shown in the following examples. These illustrations of the invention are not to be considered as limiting the invention to any particular embodiment but rather implementations of preferred embodiments. Those skilled in the art will recognize that substantial deviation is still within the scope of the invention.

#### Example 1

A new consumer Kenmore<sup>TM</sup> compact wash vessel was used in the initial experiments. Only the wash water was treated and reused. The rinse cycle used fresh

water. The wash water was microfiltered with a 0.1-micron pore size filter in a tubular membrane. The pore size treated was expected to remove particulate and emulsifier oily soil, as well as insoluble builders (zeolites), when present. A tubular membrane was resistant to fouling by particulate matter.

5        Standard test strips containing swatches of different soils were used to test cleaning ability. Redeposition swatches that were initially clean were used to test soils redepositing onto fabric. The reflectance of clothes before and after washing yields the measure of soil removal. This is the standard test in the industry.

10        A variety of measurements were made on the water at several points in the process to aid in understanding the fate of important chemicals originally present in the detergent. In order to simulate some standard or usual conditions encountered in a Laundromat facility, a ½ cup of powdered Tide™ (with builder, not with bleach) detergent was used and the temperature of wash water was about 40°C and the temperature of rinse water was about 27°C. All fresh and make-up water was  
15        maintained with a water hardness of 150 ppm of CaCO<sub>3</sub>.

The water was prepared by dissolving 50,000 mg/l (50,000 ppm) hard water, 44.13 g of CaCl<sub>2</sub>•2H<sub>2</sub>O (MW = 147.1), and 40.06 g of MgCl<sub>2</sub>•6H<sub>2</sub>O in 1 liter of deionized water. The water was then diluted with deionized water to maintain about 150 ppm hardness.

20        The following equipment and materials were also used:

Dryer (Kenmore™ model 7/60901/2/7)

Detergent: Tide™ “Free of Dyes and Perfumes”™ (Wal-Mart™  
Supercenter™)

Test strips EMPA 90 (Testfabrics, Inc.)

25        Membrane unit (0.1 micron microfilter membrane, 0.2 micro lint filter,  
ultraviolet (“UV”) lamp)

CaCl<sub>2</sub>•2H<sub>2</sub>O and MgCl<sub>2</sub>•6H<sub>2</sub>O

Sodium tripolyphosphate (STPP) (Fisher Scientific)

Hunterlab SN-7834 spectrophotometer

In each detergency experiment, two test strips were used. Each of the test strips was comprised of cotton swatches having six different kinds of soils on them. An unbleached swatch and a bleached swatch were used to examine redeposition.

5 The hot water inlet was used as the feed for the wash step and the cold water inlet for the rinse step. Initially, a cold water tank was filled with 60 gallons of tap water. After adjusting the hardness level to 150 ppm of  $\text{CaCO}_3$ , 20 gallons as previously discussed of the water in the cold water tank was transferred to a hot water tank and heated to about  $40^\circ\text{C}$ . To simulate clothes, two test strips, test strip #1 and #2, were pinned to three pounds of scoured fabric.

10 In order to scour the fabric, the fabric was cut into 45" X 23" pieces before being loosely placed into the washer. Then, 50.4 g of sodium tripoly phosphate ("STPP") was added to the wash. The wash vessel was set at regular. The machine was stopped manually after the wash cycle and before the rinse cycle. Again 50.4 g of STPP was added to the washer for the second, third, and fourth washes. For the fifth  
15 cycle, the machine was allowed to go through all the steps, including rinse and spin cycle. The scoured fabric was transferred to the dryer before storing in a clean plastic bag.

A half cup (about 87.5 g) of Tide<sup>TM</sup> detergent was poured into the wash vessel containing the scoured fabric samples. The wash cycle was carried out at about  $40^\circ\text{C}$   
20 using warm or hot water in the hot water tank. Cold water at about  $27^\circ\text{C}$  from the cold water tank was used for the rinse. After the first wash, both the 15 gal-wash water effluent and the 15 gal-rinse water effluent were transferred to a holding tank before filtering. The permeate from filtration was kept in the cold water tank to be reused for the next wash. The retentate was collected in a vessel after passing through  
25 the UV lamp to kill bacteria and circulating to get a sufficient volume. The two test strips were removed for measurement of reflectance using the Hunterlab spectrophotometer after drying. A bleached swatch of each test strip, swatch #8, was cut out from test strips and used as "redeposition swatch."

In the second wash, with the same amount of Tide<sup>TM</sup> detergent, two new test  
30 strips, test strip # 3 and 4, and redeposition swatches from the previous wash were again pinned onto a new set of about three pounds of scoured fabric. The second

wash experiment was carried out as was the first wash except that the feed water to the wash step was permeate from the filtration diluted with fresh water. The detergent dosage was not adjusted. After drying, both test strips and two redeposition swatches were removed for reflectance measurement.

5 Due to the foam problem occurring in the rinse cycle in this second wash, tap water was used in the rinse cycle without adjusting hardness in the third and subsequent washes. After the third wash, only water effluent was held in the holding tank and rinse water effluent was discarded. To get a sufficient amount of permeate for the next wash cycle, effluent wash water was mixed with about five gallons of  
10 fresh water (also at about 150 ppm hardness) before going to the filtration. The fourth and fifth washes were carried out in the same manner as the third wash. Only in the second wash was recycled water used in the rinse cycle.

Redeposition swatches were present in successive washes. For instance, swatch #8, as previously mentioned, of test strip #1 and #2 were present together with  
15 test strips #3 and #4 in the second wash. After the experiment was completed, Swatch #8 or bleached cotton was cut out from test strips #3 and 4. All redeposition swatches and test strips #5 and #6 were present in the third wash. In this manner, redeposition swatches were used over and over to examine redeposition. The following Table gives the percent soil removal per wash for various materials:

20

**TABLE 1: Percent Soil Removal**

Description	1st wash	2nd wash	3rd wash	4th wash	5th wash
Red Wine	44.31	42.33	45.82	41.84	42.91
Raw, unbleached	6.59	8.84	6.63	4.67	5.94
Immedial black	11.29	14.15	12.33	11.21	10.89
Blood, milk, carbon black	58.22	54.07	55.41	52.10	51.56
Cocoa	60.57	64.13	67.53	60.77	60.06
Blood	82.49	72.04	76.33	75.35	75.15
Carbon black, olive oil	42.57	53.49	51.50	49.78	48.98

As seen from the Table 1, the soil removal varies little over sequential washes. The following tables show that the reflectance or brightness of the redeposition swatches of the test strips appear nearly constant:

**TABLE 2: Reflectance of the Swatches**

Wash #	Test strip #		
	1,2	3,4	5,6
1	92.05	-	-
2	94.01	92	-
3	94.09	94.16	92
4	94.02	94.12	94.35
5	93.84	94.01	94.21

### **Example II**

Active matter titration was used to determine the anionic surfactant concentrations (both sulfonates and sulfates) of the experimental solutions as well as a blank. The surfactants were reacted with an aqueous solution of dye.<sup>2</sup> About 20 ml of dimidium bromide/disulphine blue indicator ("DI") stock solution, obtained from Gallard-Schlesinger Industries, Inc., was added to about 200 ml of distilled water in a one liter glass-stoppered mixing cylinder. About 3 ml of concentrated sulfuric acid mix was added and then diluted to one liter with distilled water and again mixed thoroughly. Reagent grade chloroform (Fisher Scientific) was added and the two-phase mixture was titrated with a standard aqueous solution of Hyamine 1622 (Benzethonium chloride, 98%, Lancaster synthesis).

Standard 0.0004 molar Hyamine solution was prepared by dissolving about 1.8 grams of Hyamine 1622 in distilled water and diluting to one liter. Using a 10-ml pipette, about 10 ml of sodium lauryl sulfate ("SLS") determined to have a molarity of 0.003527 was transferred to a graduated cylinder. DI water was added until 20 ml volume was reached. Then, about 20 ml mixed indicator solution and 15 ml chloroform was added.

Next, about 20 ml of surfactant solution (water sample) was added to a 100 ml graduated cylinder the weight of the solution sample was recorded. Then, about 20 ml of mixed indicator solution and 15 ml chloroform was added to the graduated cylinder. Titration was begun by adding approximately 2 ml of hyamine solution to the cylinder, capping and inverting the cylinder about 10 times, making sure all liquids were mixed. The cylinder was vented after the first inversion as some

pressure will build up and cause leakage if not vented. Hyamine solution was added in additional small quantities, mixing well after each addition. The endpoint was reached when the bottom chloroform layer changed color from pink to gray-blue.

The normality of the hyamine was calculated as follows:

5      Normality of Hyamine (N) = 
$$\frac{(10 \text{ ml SLS})(0.00327 \text{ Molarity of SLS})}{(\text{ml hyamine used in titration})}$$

At the titration end point the chloroform layer changed from pink to gray-blue.

Samples of wash water permeate were collected and kept in the refrigerator for later analysis. The wt.% active matter in the samples was calculated as follows:

10      Milli-equivalent (Meq/g) = 
$$\frac{(N)(\text{ml hyamine used})(100)}{\text{grams of sample used}}$$

$$\% \text{ AM} = \frac{(\text{meg/g})(\text{MW of the test surfactant})}{1000}$$

Total organic carbon ("TOC"), inorganic carbon ("IC"), conductivity, pH, and turbidity were measured. Atomic absorption was used to measure  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$  concentrations.

15      The active matter of the wash water, permeate, and retentate, are reflected in the following Table 3:

**TABLE 3: Active Matter**

Run No.	Sample	Active matter, ppm	Volume, gal	Active matter balance calculated from	
				Water influent to washing Machine, ppm	water effluent from filtration , ppm
-	Fresh water	-	-	-	-
1	Wash water_1	196.00	15	305.0	112.7
	Permeate_1	49.46	25		
	Retentate_1	90.66	5		
2	Wash water_2	227.51	15	354.46	180.73
	Permeate_2	68.04	20		
	Retentate_2	135.01	10		
3	Wash water_3	280.00	15	373.04	173.17
	Permeate_3	96.00	15		
	Retentate_3	231.50	5		
4	Wash water_4	277.26	15	401.00	227.89
	Permeate_4	115.92	15		
	Retentate_4	335.92	5		

"Wash water" (in column 2) = water samples collected right after wash  
 5 (water effluent from wash vessel)

"Wash water influent" = water samples containing 87.5 grams of  
 detergent and retained detergent from the  
 previous wash

"Water effluent from filtration unit" = water samples from filtration unit  
 10 downstream, number in this column refers to the  
 summation of the active matter content in the  
 permeate and the retentate.

Active matter in the wash water sample (right after wash, not including rinse  
 water) was 196 ppm. The concentration of active matter influent was 87.5 g  
 15 (composition of active matter was 19.8 wt. % ) of Tide™ detergent in fifteen gallons  
 of fresh water. Therefore, the active matter in the water influent (shown in column 5,  
 subcolumn 1) was

$$\frac{(87.5g)}{(15 * 3.79 \text{ liters})} \times 1000 \times 0.198 = 305 \text{ ppm}$$

In subcolumn 2, the numerical values were calculated from the summation of active matter content in 25 gal of permeate and that in 5 gal of retentate. A certain amount of fresh water was added into the wash water before going to the membrane unit. Accordingly, the concentration needed to be adjusted in the original volume (15 gal). Comparing active matter content with each other:

$$\frac{(49.96 * 25) + (90.66 * 5)}{30} = 56.73 \text{ ppm (after diluted)}$$

$$(56.73 * 30 / 15) = 112.7 \text{ ppm}$$

The calculation procedure for subsequent runs was the same except that the active matter calculation in "water influent to washing machine" involved a water sample that was now recycled water containing a certain amount of active matter. Consequently, the total concentration of active matter in the water in was, e.g.,

$$49.46 + 305 = 354.46 \text{ ppm}$$

The concentration of active matter in the retentate was approximately three times that of the permeate, compared to a factor of 2 in blank filtration. Surfactant emulsifying oily soil and adsorbed on particulate soil may have caused this effect. The active matter content increased with the number of runs because the permeate contained some surfactant to which a new dose was added.

The amount of active matter retained in the clothes was calculated by:

[active matter in water influent to washing machine, shown in subcolumn 1]

- [active matter in wash water, shown in column 3].

For example, for run #1,

$$[\text{active matter retained in the clothes}] = 305 - 196 = 109 \text{ ppm}$$

% retained (based on the water influent to washing machine) =

$$109 / 305 * 100 = 35.72\%$$

The amount of active matter retained in the membrane unit was calculated by

[active matter in water before going to the filtration unit, shown in column 3]

-[active matter in water effluent from filtration, shown in subcolumn 2]

For example, run # 1,

[active matter retained in the filtration unit] =  $196 - 112.7 = 83.3$

ppm

% retained (based on the water inlet of filtration) =

$83.3/196 \times 100 = 83.3$  ppm

Approximately 2/3 of the original surfactant was in the wash water effluent and 1/3 in the clothing and accompanying retained water:

**TABLE 4: Amount of Active Matter Retained**

Run No.	Amount of active matter retained in			
	Clothes*		filtration unit**	
	ppm	%	ppm	%
1	109	35.74	84	42.86
2	127	35.83	46.8	20.57
3	93	24.93	106.8	38.14
4	123.7	30.85	49.4	17.82

\* Numbers represented as the difference amount of active matter in ppm and percent of the wash influent and effluent

\*\* Numbers represented as the difference amount of active matter in ppm and percent of the filtration upstream and downstream

The TOC of the water effluent increased with number of runs faster than active matter, possibly due accumulation of oily soil. Inorganic carbon level increased mildly with number of washes (more slowly than TOC) and only mildly greater retentate IC is seen compared to permeate IC.

The permeate was so clean that its turbidity was negligible. The turbidity of wash effluent and retentate did not vary much with number of washes. Conductivity and pH increased with the number of washes, possibly because alkali was added with fresh detergent in each load. Since builder was added with each load also,  $[Ca^{+2}]$  and

[Mg<sup>+2</sup>] decreased with sequential washes. Since the surfactant concentration in all streams was above the critical micelle concentration ("CMC"), the surface tension was approximately the same for the solutions analyzed as shown in FIG. 5.

### Example III

5 Two 0.1 micron membranes (PEF 4172, area 0.17 m<sup>2</sup>) from Stork were used in these experiments. These membranes should produce a flux of 1000 L per m<sup>2</sup> per hour (= 2.8 L/min) for pure water at the operating pressure of about 100 KPa. Initial tap water flux for these membranes was determined to be about 1 L/min at 30 psig feed pressure when they were installed in the filtration system.

10 The first membrane was previously used for the treatment of wash water effluents from the wash vessel. Because of this, the first membrane was washed, treated with 100 ppm bleach, and back flushed with tap water. Four filtration experiments with the first membrane and two experiments with the second membrane were performed.

15 The second membrane had previously been used to filter the wash sequence with Liquid Tide™ detergent in soft water. The second membrane was not bleach treated or back flushed since it was a new membrane when the liquid Tide HE™ detergent in soft water was filtered. However, the second membrane was cleaned extensively including bleach treatment and back flushing with tap water before  
20 filtering SDS in soft water. The back flushing procedure dislodged a substantial quantity of brown/gray slime from the inside of the membrane tubes.

For all experiments, a reservoir connected to the filtration system was filled with soft tap water to the 10.5 gallon mark and tap water was circulated through the system at a rate of about 5.4 gal/min (27 psig feed pressure) until an equilibrium flux  
25 was obtained. After the soft tap water flux reached equilibrium, surfactant or detergent was added and an equilibrium flux was established. If hardness (150 ppm as CaCO<sub>3</sub>) was to be added, then a weighed amount of solid mixed chlorides (Ca/Mg = 3/2) was slowly added and a new equilibrium flux was established. Permeate and feed/retentate samples were taken at each equilibrium point, which dropped the water  
30 level in reservoir to 10 gallons.

The permeate hose, which had been recycling to the reservoir, was moved to a separate container and about 2.5 gallons of composite permeate was removed from the system. After collection of the composite permeate, the hose was returned to the tank, flux measurement was made with a graduated cylinder, and samples of permeate and feed/retentate were collected (7.5 gallon point). The permeate hose was then moved to another empty container to collect a second composite permeate (about 7.5 gallons to about 5 gallons) and returned to the reservoir for flux measurement and sample collection. Similarly, a collection of third composite permeate (about 5 gallons to about 2.5 gallons) was done.

At this point, the filtration system contained about 2.5 gallons of feed/retentate and three different containers had permeate volumes of 2.5 gallons. When all samples were taken, all three of the permeate volumes were poured back into the reservoir (reconstituted system) containing only slightly less fluid than the original. Flux measurement was made and samples were collected from the reconstituted system.

TOC and active matter analysis of water samples were performed.

The membrane flux for first and second membranes with tap water was about 700 – about 1000 ml/min and about 1110 - about 1250 mL/min, respectively. When the SDS, powder Tide HE™ detergent or liquid Tide HE™ detergent was added to water, the flux dropped immediately to about 50 % of the tap water value with a feed flow in all cases of 5.4 gallon/min, as shown in the following table and graphically in FIG. 6:

**TABLE 5: Flux**

Filtration System	Flux (mL/min)		
	Tap water	Detergent Addition	Hardness
Sodium Dodecyl Sulfate with soft water (first membrane)	810	500	-
Liquid Tide HE with soft water (first membrane)	890	540	
Liquid Tide HE with hard water (first membrane)	680	320	195
Powdered Tide HE with hard water (first membrane)	970	380	170

Filtration System	Flux (mL/min)		
	Tap water	Detergent Addition	Hardness
Liquid Tide HE with soft water (second membrane)	1110	810	
Sodium Dodecyl Sulfate with soft water (second membrane)	1740	690	

A further drop in flux was observed when hardness was added. For example, tap water flux (membrane 1) of about 680 ml/min dropped to about 320 ml/min with the addition of liquid Tide HE™ detergent, and further dropped to about 195 ml/min after hardness was added (this process took about 1.5 hours to reach equilibrium). Tap water flux (membrane 1) of about 970 ml/min dropped to about 380 ml/min with the addition of powder Tide HE™ detergent, and further dropped to about 170 ml/min after hardness was added. Hence, there is a penalty for flux when particulate matter is present in the filtration feed. With liquid Tide™ detergent, the particulate matter increases because of added hardness that is possibly soap precipitation. With powder Tide™ detergent, the particulate matter is primarily zeolite and adding hardness seems to make the problem worse.

When 75% of the feed volume was removed (about 10 gallons to about 2.5 gallons) as permeate, the flux dropped about 17 - about 44 % (depending on the system) of the flux at the 10 gallon level. When the three permeate volumes were poured back into the reservoir, the flux increased but did not reach the starting value.

The second membrane had relatively high flux with tap water (about 25% higher than the first membrane). The observations with the second membrane are not unusual in view of the number of cycles the first membrane endured, which included the filtration of zeolite and other mixtures.

Active matter was measured by titration SLS, Hyamine 1622, mixed indicator, chloroform, concentrated sulfuric acid, and TOC was measured using DC 180-Rosemount.

The following Table reflects the active matter results.

**TABLE 6: First Membrane Active Matter**

Active Matter (ppm)	SDS in soft water		Liquid Tide HE In soft water		Liquid Tide HE In hard water		Powder Tide HE In hard water	
Feed volume (G)	Feed (retentate)	Permeate	Feed (retentate)	permeate	Feed (retentate)	permeate	Feed (retentate)	permeate
10	1140	333	338	213	293	179	250	73
7.5	1200	431	197	326	312	196	303	56
5	1270	517	390	205	351	189	496	72
2.5	1680	776	508	276	512	207	712	82

The following Table reflects the TOC analysis.

**TABLE 7: First Membrane TOC Analysis**

TOC (ppm)	SDS in soft water		Liquid Tide HE In soft water		Liquid Tide HE In hard water		Powder Tide HE In hard water	
Feed volume (G)	Feed (retentate)	Permeate	Feed (retentate)	permeate	Feed (retentate)	permeate	Feed (retentate)	permeate
10	1384	525	1029	753	1083	828	583	175
7.5	1727	559	1094	777	1136	778	708	171
5	2270	673	1256	831	1290	789	1049	190
2.5	3349	1023	1572	967	1706	834	1500	214

5

**TABLE 8: Second Membrane TOC Analysis**

TOC (ppm)	Liquid Tide HE In soft water		SDS in soft water	
	Feed volume (G)	Feed (retentate) Permeate	Feed (retentate)	permeate
10		999 973	2083	1878
7.5		1053 971	2148	1805
5		1096 993	2371	1872
2.5		1130 1016	2612	1914

The active matter and TOC measurements are qualitatively consistent even though the TOC measurement detects citrate in liquid Tide™ detergent and nonionic surfactant in detergent that the active matter does not. The qualitative trend between active matter and TOC for the SDS is not as consistent as for the other samples (the SDS permeate samples developed cloudiness while awaiting AM titration analysis). All detergent samples showed increased retention of surfactant as the original 10 gallon volume was reduced by the removal of permeate from the system. After removal of about 75% of the 10 gallon volume as permeate, the powder Tide™ detergent samples showed a more extreme case of surfactant retention in the feed/retentate solution (the active matter and TOC ratio of feed to permeate (F/P) reached a value of 8.68 and 7.01, respectively).

15

**TABLE 9: Feed to Permeate Ratio**

	SDS in soft water First membrane		Liquid Tide HE In soft water First membrane		Liquid Tide HE In hard water First membrane		Powder Tide HE In hard water First membrane		Liquid Tide HE In soft water Second membrane	SDS in soft water Second membrane
Feed volume (G)	F/P (AM)	F/P (TOC)	F/P (AM)	F/P (TOC)	F/P (AM)	F/P (TOC)	F/P (AM)	F/P (TOC)	F/P (TOC)	F/P (TOC)
10	3.42	2.64	1.59	1.37	1.64	1.31	3.42	3.33	1.03	1.11
7.5	2.78	3.09	1.65	1.41	1.59	1.46	5.41	4.14	1.08	1.19
5	2.46	3.37	1.9	1.51	1.86	1.63	6.88	5.52	1.10 <sup>3</sup>	1.27
2.5	2.16	3.27	1.84	1.63	2.47	2.05	8.68	7.01	1.11	1.36

The precipitate particles present in the Liquid Tide™ detergent with hardness samples showed a lower degree of effect in increasing the F/P ratio of the surfactant. With the second membrane, the surfactant retention was also increased as the volume of feed solution reduced but less amount of surfactant was retained in the feed/retentate solution.

The presence of particulate matter had a marked effect on membrane flux and on surfactant concentration in the permeate. Both relative flux and the permeate surfactant concentrations were lowered in the presence of particulates. Both membranes acted more like an ultrafiltration membrane than like a microfiltration membrane. The reduced water and active matter flux observed when using hard water and/or powder detergent containing insoluble zeolite particles indicates that use of liquid detergent and soft water is a preferred embodiment of the invention.

#### Example IV

Five sets of detergency experiments (details discussed below) were performed using a Maytag Neptune™ horizontal axis wash vessel. In each detergency experiment, five pounds of freshly scoured cotton fabric on which test strips were  
5 pinned was used to simulate the clothes.

In order to scour the fabric, five pounds of fabric (size of each piece: 36 inch x 36 inch) were loosely placed into the Kenmore™ portable washer. Then, 50.4 g of STPP was added to the wash. The wash vessel was set at regular. The machine was stopped manually after the wash cycle and before the rinse cycle. Again, 50.4 g. of  
10 STPP was added into the washer for the second, third, and fourth wash cycles. For the fifth cycle, the machine was allowed to go through all the steps, including rinse and spin cycle. The fabric was transferred to the dryer before storing in a clean plastic bag.

Warm water (about 40° C) was used for the wash cycle. Cold water (about 27°  
15 C) was used for the three rinse cycles. The Neptune™ wash vessel was set to whites for fabrics and the wash cycle was carried out at regular (normal wash) mode. The wash water and rinse water effluents were collected separately in holding tanks after passing through a wire mesh (used for lint separation). The wire mesh was not used for the set 1 experiments. The reflectance of washed swatches was measured using a  
20 Hunterlab™ spectrophotometer. For all washes, the standard dosage of detergent for a normal wash was used and the detergent dosage was not adjusted during the sequence. The microfiltration membrane unit was cleaned by flushing it with tap water for several minutes between rinse (set 3-5) and wash (set 1-5) filtrations, and the wash sequences for each set. However, it was back flushed with tap water  
25 between the sets. One membrane was used to filter both rinse and wash waters (set 3, 4, and 5).

Initial experiments used powder Tide HE™ detergent for washing in water with added Ca/Mg hardness to the extent of 150 ppm. Liquid fabric softener (Downy™ softener) was also added. Later washes in this sequence employed liquid  
30 Tide HE™ detergent with soft water and no added fabric softener. This change was prompted by the expectation that soft water would improve washing effectiveness and

by the detrimental effect of the zeolite builder in powdered Tide™ detergent on filtration processes.

5 A washing sequence typically included a total of six washes and five filtrations. The first wash in each sequence used fresh water. Subsequent washes used filtered/recycled water for wash and rinse steps. Standard test strips (e.g., EMPA 103) and redeposition swatches were included in each wash and examined by reflectance measurements to determine washing effectiveness. Fluid samples from the wash, rinse, and filtration steps were analyzed for active matter (detergent) and TOC.

10 Filtration of the wash/rinse fluids was done with a Stork™ 0.1-micron microfiltration membrane. Several experiments were carried out to determine filtration effectiveness in the absence of wash-produced soil/particulates. These experiments utilized either liquid or powdered Tide™ detergent or a sodium dodecyl sulfate mixture.

15 The use of chlorine bleach or peroxygen bleach was also assessed in several washing procedures. Chlorine bleach seemed to be most effective with the peroxygen bleach showing poorer performance even at elevated washing temperatures.

20 In each detergency experiment, two test strips of "EMPA 103" were used. A bleached swatch of EMPA 103 was put through the sequence of six washes to examine redeposition.

The following are the sets of conditions used:

25 Set 1: Hard water; powdered detergent; wash temperature about 40° C, rinse temperature-room temperature; 60% wash water recovery after microfiltration; 60% rinse water recovery after bag filter (0.45 micron pore size) filtration; rinse-added fabric softener. Six runs were made.

30 FIG. 1 shows the process flow diagram for the apparatus of Set 1. The hot water inlet 22 was used as the feed for the wash step and the cold water inlet 24 was for the rinse step. The hardness level of the water in wash water feed tank 42 was adjusted to 150 ppm as CaCO<sub>3</sub> and water was heated to about 40° C with a steam coil. A half cup (about 87.5 g) of Tide HE™ detergent and a standard dosage (about 28.27 g) of Downy™ fabric softener were placed in the wash and rinse dispensers. After

the wash cycle, the wash water effluent (about 3.8 gallons) was collected in a holding tank 32 where the wash water effluent was mixed with about 0.7 gallon of fresh hard water (150 ppm as  $\text{CaCO}_3$ ) prior to its filtration. Three rinse water effluents (about 16 gallons) were transferred to a holding tank 32.

5        The wash effluent held in holding tank 32 was filtered with the tubular 0.1-micron micro filtration filter 36. The permeate, or solution passing through the filter 36 (about 3.75 gallons), was passed to tank 42 mixed with about 1.25 gallon of fresh hard water (150 ppm as  $\text{CaCO}_3$ ), and reused for the next wash. The retentate, or solution not passing through the filter 36, after circulating to get a sufficient volume  
10        was held in holding tank 32 and was discarded (about 0.75 gallons) upon completion of filtration.

         Although the initial plan for the rinse effluent was dilution and reuse, fabric and other particles plugged the screen on washer inlet line 24, so a 0.45 micron bag filter 54 had to be used to treat the rinse water prior to dilution and reuse. The rinse  
15        effluent 46 (about 16 gallons) was transferred from holding tank 48 to mixing tank 52 where it was mixed with 10 gallon of fresh hard water and treated with the bag filter 54.

         A total of six washes and five filtration experiments were performed. Water samples collected from several points of the unit were analyzed for TOC, IC (wash  
20        influent, wash effluent, wash permeate, wash retentate, rinse influent, and rinse effluent) and for active matter (sulfate/sulfonate) content (wash effluent, first rinse, wash permeate, and wash retentate). The two test strips after the wash were air-dried before measuring reflectance using the Hunterlab™ spectrophotometer at the specular excluded reflectance mode. Swatch #8 or a bleached swatch of each test strip was cut  
25        out from the test strips and were used as “redeposition swatch.”

         Active matter titration was used to determine the anionic surfactant (both sulfonates and sulfates) concentrations and the results are shown in FIGs. 23–26.

         For the Set 1 and 2 experiments, active matter of the retentate was approximately 12.4 times that of the permeate, compared to a factor of 8.7 in blank  
30        filtration of powder Tide HE detergent in hard water. The following are the active matter results for Set 1:

**TABLE 10: Active matter balance of set 1 water samples**

Wash	Water samples	Active Matter	Volume	Active Matter	Amount of active matter retained	
		(ppm)	(gal)	(g)	On clothes after wash (g)*	In filtration unit (g)**
1	Detergent dosage	929.326288	5	17.59		
	Wash water effluent	555.49	3.8	7.99	9.60	3.52
	First rinse	88.58	5.5	1.84		
	Permeate (wash)	169.85	3.75	2.41		
	Retentate (wash)	723.78	0.75	2.05		
2	Wash water effluent	578.89	3.8	8.33		
	First rinse	118.06	5.5	2.46	11.67	2.81
	Permeate (wash)	176.83	3.75	2.51		
	Retentate (wash)	1058.22	0.75	3.00		
3	Wash water effluent	601.84	3.8	8.66		
	First rinse	160.58	5.5	3.34	11.44	3.04
	Permeate (wash)	136.27	3.75	1.93		
	Retentate (wash)	1297.69	0.75	3.68		
4	Wash water effluent	582.85	3	6.62		
	First rinse	160.38	5.5	3.34	12.90	0.98
	Permeate (wash)	111.39	3.75	1.58		
	Retentate (wash)	1430.79	0.75	4.06		
5	Wash water effluent	589.05	3.8	8.47		
	First rinse	141.98	5.5	2.96	10.70	2.77
	Permeate (wash)	115.77	3.75	1.64		
	Retentate (wash)	1430.22	0.75	4.06		
6	Wash water effluent	544.92	3.8	7.84		
	First rinse	152.36	5.5	3.17	11.39	

\* Number represents the difference between active matter content of wash water influent with added dose and wash water effluent

5 \*\* Number represents the difference between active matter content of filtration unit upstream and downstream

**TABLE 11: Active matter retained on clothes and in the membrane unit (set 1)**

Wash #	Amount of active matter retained		AM Recycled with wash permeate
	on clothes after wash (%) ***	in filtration unit (%)****	%
1	54.57	44.11	13.71
2	58.37	33.78	12.55
3	56.93	35.10	9.62
4	66.10	14.74	8.10
5	55.80	34.89	8.57
6	59.24		

\*\*\* numbers represent as percent difference between active matter content of wash water influent with added dose and wash water effluent

5 \*\*\*\* numbers represent as percent difference between active matter content of filtration unit upstream and down stream

Set 2: Hard water; powdered detergent; wash temperature about 40° C, rinse temperature-room temperature; 60% wash water recovery after microfiltration; 80 to 10 95% rinse water recovery after bag filter filtration; rinse-added fabric softener. Nine runs were made.

Experimental conditions for set 2 were similar to those of set 1 with a few exceptions, shown in the configuration of FIG. 2, such as all three rinse effluents were collected in the rinse tank 52, which had an initial content of 20 gal. fresh hard water, 15 and reused without adding fresh make up water and using bag filter. Fresh hard water (about 2 gallons) was added to the wash effluent when the wash effluent was in tank 32 prior to filtration. A total of nine washes and eight filtration experiments were performed.

Active matter titration was used to determine the anionic surfactant (both 20 sulfonates and sulfates) concentrations, with the following results:

**TABLE 12: Active matter balance of set 2 water samples**

Wash	Water samples	Active Matter	Volume	Active Matter	Amount of active matter retained	
		(ppm)	(gal)	(g)	on clothes after wash (g)*	in filtration unit (g)**
1	Wash water influent	929.326288	5	17.59		
	Wash water effluent	350.98	3.8	5.05	12.54	1.75
	Rinse effluent	37.34	16	2.26		
	Permeate (wash)	85.74	5	1.62		
	Retentate (wash)	591.33	0.75	1.68		
2	Wash water effluent	423.89	3.8	6.10		
	Rinse effluent	50.09	16	3.03	13.11	1.30
	Permeate (wash)	88.78	5	1.68		
	Retentate (wash)	1099.11	0.75	3.12		
3	Wash water effluent	434.51	3.8	6.25		
	Rinse effluent	53.72	16	3.25	13.02	1.48
	Permeate (wash)	90.55	5	1.71		
	Retentate (wash)	1076.53	0.75	3.06		
4	Wash water effluent	434.84	3.8	6.25		
	Rinse effluent	70.21	16	4.25	13.05	1.20
	Permeate (wash)	105.52	5	2.00		
	Retentate (wash)	1077.24	0.75	3.06		
5	Wash water effluent	454.73	3.8	6.54		
	Rinse effluent	93.06	16	5.64	13.04	1.61
	Permeate (wash)	87.53	5	1.66		
	Retentate (wash)	1154.01	0.75	3.28		
6	Wash water effluent	567.67	4	8.59		
	Rinse effluent	109.82	16	6.65	10.65	3.56
	Permeate (wash)	103.94	5	1.97		
	Retentate (wash)	1081.44	0.75	3.07		
7	Wash water effluent	578.89	3.8	8.33		
	Rinse effluent	119.58	16	7.24	11.23	2.65
	Permeate (wash)	102.46	5	1.94		
	Retentate (wash)	1316.00	0.75	3.74		
8	Wash water effluent	585.41	3.8	8.42		
	First rinse	126.30	16	7.65	11.11	2.48
	Permeate (wash)	107.27	5	2.03		
	Retentate (wash)	1375.86	0.75	3.91		
9	Wash water effluent	603.15	3.8	8.68		
	Rinse effluent	133.32	16	8.07	10.94	2.48

**TABLE 13: Active matter retained on clothes and in the membrane unit (set 2)**

wash #	Amount of active matter retained in		AM Recycled with
	Clothes after wash (%)***	Filtration Unit (%)****	wash permeate (%)
1	71.30	34.60	9.23
2	55.37	21.27	8.75
3	54.61	23.68	8.89
4	54.72	19.18	10.35
5	54.06	24.59	8.46
6	40.67	41.39	10.22
7	43.33	31.84	9.92
8	42.70	29.50	10.40
9	41.67	28.58	11.04

5        Set 3: Soft water; liquid detergent; wash temperature about 40° C, rinse temperature-room temperature; 60% wash water recovery after microfiltration; 80% rinse water recovery after microfiltration; no fabric softener added; “Surfactant-sensitive” swatches added in addition to other swatches; UV filter used in reflectance measurements to avoid fluorescent brighteners skewing results. Six runs were made.

10        The experimental flow chart of set 3 is shown in FIG. 3. Liquid Tide HE™ detergent was used at the dosage for a normal wash (about 98 g). For this set, soft tap water was used for wash and rinse cycles. Fabric softener was not used.

15        Besides EMPA 103, two sets of three soiled swatches (EMPA 116, Cotton 400, and Cotton PEDP 7435 WRL) were washed. Reflectance of swatches before and after the wash was measured with the Hunterlab spectrophotometer at the specular included reflectance mode. The UV filter was also included during the reflectance measurements in order to eliminate the effect of detergent brightener on the reflectance.

20        Six washes and five filtration experiments were performed. The rinse effluent (about 16 gallons) was filtered with the microfiltration unit and the permeate stream (about 14 gallons) was collected in the rinse water holding tank. Three gallons of

fresh soft water was added to the rinse effluent permeate before it was reused for the next wash. The same microfiltration unit was used to treat the wash water effluent in FIG. 3.

For the set 3 and 4 experiments, active matter of the retentate is approximately 9 times that of the permeate, compared to a factor of 2 in blank filtration of liquid Tide HE™ detergent in soft water. Surfactant emulsifying oily soil and adsorption on particulate soil could explain the increase in retained surfactant concentration in the retentate streams. However, the active matter content of the retentate is approximately three times that of the permeate for set 5.

The following are the active matter results for Set 3:

**TABLE 14: Active matter balance of set 3 water samples**

Wash	Water samples	Active Matter (ppm)	Volume (gal)	Active Matter (g)	Amount of active matter retained	
					on clothes after (wash) (rinse) (g)*	in filtration unit (wash) (rinse) (g)**
1	Wash water influent	1180.660502	5	22.34		
	Wash water effluent	694.09	3.8	9.98	12.36	4.53
	Rinse effluent	53.85	16	3.26	9.10	
	Permeate (wash)	98.94	5	1.87		
	Retentate (wash)	1181.14	0.8	3.58		
	Permeate (rinse)	24.76	14	1.31		1.26
	Retentate (rinse)	90.81	2	0.69		
2	Wash water effluent	825.69	3.8	11.88		
	Rinse effluent	98.05	16	5.94	12.34	4.90
	Permeate (wash)	151.87	5	2.87	7.71	

Wash	Water samples	Active Matter (ppm)	Volume (gal)	Active Matter (g)	Amount of active matter retained	
					on clothes after (wash) (rinse) (g)*	in filtration unit (wash) (rinse) (g)**
	Retentate (wash)	1355.98	0.8	4.11		
	Permeate (rinse)	70.37	14	3.73		0.84
	Retentate (rinse)	180.50	2	1.37		
3	Wash water effluent	919.16	3.8	13.22		
	Rinse effluent	115.09	16	6.97	12.00	5.81
	Permeate (wash)	165.25	5	3.13	8.76	
	Retentate (wash)	1416.09	0.8	4.29		
	Permeate (rinse)	81.39	14	4.31		-0.03
	Retentate (rinse)	354.38	2	2.68		
	Wash water effluent	780.00	3.8	11.22		
4	Rinse effluent	141.20	16	8.55	14.25	3.90
	Permeate (wash)	159.67	5	3.02	10.01	
	Retentate (wash)	1419.29	0.8	4.30		
	Permeate (rinse)	103.65	14	5.49		0.43
	Retentate (rinse)	347.60	2	2.63		
	Wash water effluent	982.58	3.8	14.13		
	Rinse effluent	155.39	16	9.41	11.23	4.74
5	Permeate (wash)	222.67	5	4.21	7.32	
	Retentate (wash)	1709.00	0.8	5.17		

Wash	Water samples	Active Matter (ppm)	Volume (gal)	Active Matter (g)	Amount of active matter retained	
					on clothes after (wash) (rinse) (g)*	in filtration unit (wash) (rinse) (g)**
	Permeate (rinse)	112.21	14	5.95		0.30
	Retentate (rinse)	418.56	2	3.17		
6	Wash water effluent	877.810023	3.8	12.63	13.93	
	rinse water effluent	151.8028931	16	9.19	10.69	

The follow table shows the active matter retained on clothes and in the membrane unit.

**TABLE 15: Active matter retained on clothes and in the membrane unit (Set 3)**

wash #	Amount of active matter retained			AM Recycled with wash permeate
	On clothes after wash (%)***	In filtration Unit (%) - wash****	In filtration Unit (%), rinse****	%
1	55.32	45.42	38.69	8.38
2	50.96	41.23	14.20	11.87
3	47.58	43.91	-0.37	12.40
4	55.96	34.76	5.00	11.86
5	44.29	33.57	3.14	16.61
6	52.46			

5

Set 4: Soft water; liquid detergent; wash temperature about 40° C, rinse temperature-room temperature; 60% wash water recovery after microfiltration; 80% rinse water recovery after microfiltration; integration of rinse and wash water recovery systems-retentate from rinse water filtration was used instead of fresh water feed to the wash water recycle system; no fabric softener added; six runs were made.

10

The following are the active matter results for Set 4:

**TABLE 16: Active matter of set 4 water samples**

Wash	Water samples	Active Matter (ppm)	Volume (gal)	Active Matter (g)	Amount of active matter retained	
					on clothes after (wash) (rinse) (g)	in filtration unit (wash) (rinse) (g)
1	Wash water influent	1180.660502	5	22.34		
	Wash water effluent	703.67	3.8	10.12	12.22	4.63
	Rinse effluent	59.90	16	3.63	8.60	
	Permeate (wash)	132.44	5	2.51		
	Retentate (wash)	1190.03	0.8	3.60		
	Permeate (rinse)	28.00	14	1.48		1.53
2	Retentate (rinse)	81.31	2	0.62		
	Wash water effluent	879.65	3.8	12.65		
	Rinse effluent	86.80	16	5.26	12.20	3.89
	Permeate (wash)	174.10	5	3.29	8.43	
	Retentate (wash)	1805.08	0.8	5.47		
	Permeate (rinse)	83.51	14	4.43		
3	Retentate (rinse)	0.00	2			
	Wash water effluent	716.30	3.8	10.30		
	Rinse effluent	120.56	16	7.30	15.34	2.70
	Permeate (wash)	212.67	5	4.02	12.46	
	Retentate (wash)	1897.44	0.8	5.75		
	Permeate (rinse)	75.08	14	3.98		1.15

Wash	Water samples	Active Matter (ppm)	Volume (gal)	Active Matter (g)	Amount of active matter retained	
					on clothes after (wash) (rinse) (g)	in filtration unit (wash) (rinse) (g)
	Retentate (rinse)	286.35	2	2.17		
4	Wash water effluent	720.24	3.8	10.36		
	Rinse effluent	123.63	16	7.49	16.01	1.78
	Permeate (wash)	234.65	5	4.44	12.50	
	Retentate (wash)	2116.87	0.8	6.41		
	Permeate (rinse)	84.74	14	4.49		0.73
	Retentate (rinse)	299.95	2	2.27		
5	Wash water effluent	767.02	3.8	11.03		
	Rinse effluent	124.32	16	7.53	15.75	2.34
	Permeate (wash)	238.17	5	4.51	12.71	
	Retentate (wash)	2148.57	0.8	6.51		
	Permeate (rinse)	94.14	14	4.99		0.22
	Retentate (rinse)	306.79	2	2.32		
6	Wash water effluent	982.0709357	3.8	14.13	12.73	
	rinse water effluent	137.2744571	16	8.31	9.40	

The following table shows the active matter retained on clothes and in the membrane unit.

**TABLE 17: Active matter retained on clothes and in the membrane unit (Set 4)**

	Amount of active matter retained in			AM Recycled with wash permeate
wash #	Clothes after wash (%)***	Filtration Unit (%) - wash****	Filtration Unit (%), rinse****	%
1	54.70	45.71	42.12	11.22
2	49.09	30.76		13.26
3	59.82	26.21	15.82	15.70
4	60.71	17.17	9.69	16.84
5	58.81	21.22	2.89	16.83
6	47.40			

Set 5: Soft water; liquid detergent; wash temperature about 40° C, rinse temperature-room temperature; 60% wash water recovery after microfiltration; 80% rinse water recovery after microfiltration; integration of rinse and wash water recovery systems-retentate from rinse water filtration was used instead of fresh water feed to the wash water recycle system; chlorine bleach was used; dryer-added fabric softener sheets used. Six runs were made.

The following are the active matter results for Set 5:

**TABLE 18: Active matter of set 5 water samples**

Wash	Water samples	Active Matter	Volume	Active Matter	Amount of active matter retained	
		(ppm)	(gal)	(g)	On clothes after (wash) (rinse) (g)	In filtration unit (wash) (rinse) (g)
1	Wash water influent	1180.66050	5	22.34		

Wash	Water samples	Active Matter (ppm)	Volume (gal)	Active Matter (g)	Amount of active matter retained	
					On clothes after (wash) (rinse) (g)	In filtration unit (wash) (rinse) (g)
	Wash water effluent	723.27	3.8	10.40	11.94	-2.75
	Rinse effluent	102.39	16	6.20	5.74	
	Permeate (wash)	510.14	5	9.65		
	Retentate (wash)	1531.71	0.8	4.64		
	Permeate (rinse)	76.01	14	4.03		1.03
	Retentate (rinse)	151.09	2	1.14		
2	Wash water effluent	1068.69	3.8	15.37		
	Rinse effluent	171.55	16	10.39	16.63	-0.12
	Permeate (wash)	572.16	5	10.83	10.27	
	Retentate (wash)	1541.35	0.8	4.67		
	Permeate (rinse)	157.71	14	8.36		-0.06
	Retentate (rinse)	276.84	2	2.10		
3	Wash water effluent	1305.70	3.8	18.78		
	Rinse effluent	238.64	16	14.45	14.39	5.62
	Permeate (wash)	437.89	5	8.29	8.30	
	Retentate (wash)	2976.71	0.8	9.01		
	Permeate (rinse)	182.66	14	9.68		0.63
	Retentate (rinse)	546.72	2	4.14		
4	Wash water effluent	1359.88	3.8	19.56		
	Rinse effluent	262.30	16	15.89	11.07	3.46
	Permeate (wash)	656.63	5	12.43	4.87	

Wash	Water samples	Active Matter	Volume	Active Matter	Amount of active matter retained	
		(ppm)	(gal)	(g)	On clothes after (wash) (rinse) (g)	In filtration unit (wash) (rinse) (g)
	Retentate (wash)	2437.95	0.8	7.38		
	Permeate (rinse)	224.56	14	11.90		0.28
	Retentate (rinse)	490.14	2	3.71		
5	Wash water effluent	1302.58	3.8	18.74		
	Rinse effluent	285.29	16	17.28	16.04	4.33
	Permeate (wash)	566.58	5	10.72	10.66	
	Retentate (wash)	2095.18	0.8	6.34		
	Permeate (rinse)	343.74	14	18.21		3.60
	Retentate (rinse)	351.57	2	2.66		
6	Wash water effluent	1419.38	3.8	20.42	12.65	
	rinse water effluent	344.22	16	20.85	10.02	

The following shows the active matter retained on clothes and in the membrane unit.

**TABLE 19: Active matter retained on clothes and in the membrane unit (Set 5)**

	Amount of active matter retained in			AM Recycled with wash permeate
wash #	Clothes after wash (%)***	Filtration Unit (%) - wash****	Filtration Unit (%), rinse****	%
1	53.44	26.4	16.60	43.21
2	51.96	0.28	0.61	33.84
3	43.39	29.91	4.39	24.98
4	36.15	17.69	1.73	40.57
5	46.12	23.11	20.83	30.84
6	38.26			

Experimental conditions for set 4 and 5 were similar to those of set 3. However, the wash water effluent was integrated with the rinse water retentate (2 gallons ) prior to filtration as shown in FIG. 4. Hence, using fresh water as make-up  
5 water was eliminated for the wash water filtration loop.

The effect of using bleach (chlorine bleach, Ultra Clorox™ bleach) and fabric softener sheet on detergency was also studied in the set 5 experiments. The standard dosage of Ultra Clorox™ bleach for a normal load (3/4 cup = 180.66 g) was placed in the bleach dispenser of the wash vessel.

10 In addition to soiled swatches, four pieces of EMPA 223 (redeposition swatch) were used for each wash. Two pieces of EMPA 223 were dried with a fabric softener sheet (Bounce™ softener) and all the other swatches were dried using a dryer for ten or fifteen minutes without a fabric softener sheet. All swatches were ironed before the reflectance measurements. All pieces of EMPA 223 were recycled to the next  
15 wash. Rewashed redeposition swatches were dried with a fabric softener sheet only if they were previously dried with a fabric softener sheet.

As seen in FIGs. 7–16, the soil removal varies little over sequential washes for each set. Liquid Tide HE™ detergent in soft water (Sets 3 and 4) performs better soil removal than the powdered Tide HE™ detergent in hard water (Set 2) for red wine  
20 (15-20% better), blood-milk-carbon black (15-20% better), cocoa (4-9% better), blood (15-20% better), and carbon black-olive oil (5-8% better). However, the soil removal of immedial black and raw-unbleached with the use of liquid Tide HE™ detergent decreases about 1- 3% and 2-5%, respectively. Residual chlorine bleach in the reused water stream (set 5) contributes to overall cleaning except for cocoa and bloodstains.  
25 The soil removal of immedial black increases about 60% (comparison between Set 5 and 4) with chlorine bleach for the first wash and increases further with the reuse of water (for example: 71% with the 6th wash). This is probably due to the presence of residual chlorine bleach in the reused water.

The Set 2 water reuse system when compared with the Set 1 water reuse  
30 system improves the soil removal of red wine by 10%, raw-unbleached by 4%, blood-milk-carbon black by 5%, and cocoa by 10% even though the wash conditions

are same for both systems. Wash conditions and water reuse system for the set 3 and 4 were kept same but the rinse retentate was integrated with the wash effluent prior to filtration for the set 4 water reuse system (refer to FIGs. 2-3). This difference decreases the soil removal of red wine by 6%, raw-unbleached by 1%, blood-milk-carbon black by 2%, blood-milk-carbon black (smaller swatch) by 3-7.5%, dust sebum on cotton by 8-17%, dust sebum (on cotton PEDP) by 3-7%, and carbon black-olive oil by 2-5%.

The reflectance or brightness of the redeposition swatches decreases for all the sets except Set 5 as seen in FIGs. 17-22. For Set 5, reflectance of redeposition swatches appears nearly constant due to the presence of chlorine bleach in the system as shown in FIGs. 21-22.

TOC amount of set 5 wash permeate is twice that of the set 4 wash permeate samples as shown in FIGs. 29-30. The presence of chlorine might explain the increase in surfactant concentration for set 5 wash permeate streams. Either the chlorine concentration in the feed stream is over the chlorine tolerance level of the membrane (membrane will be damaged) or chlorine disrupts the detergent gel layer formed on the membrane (more surfactant will pass through membrane). The active matter content increased with the number of runs because the permeate contained residual surfactant to which a new dose was added.

About 10% of the initial surfactant used is recovered for reuse when the wash water is treated with Set 1 and Set 2 filtration systems (powdered Tide HE™ detergent in hard water used). Set 3 wash filtration unit recovers about 12% of initial surfactant for reuse (liquid Tide HE™ detergent in soft water). Integrating rinse retentate with wash water effluent prior to filtration increases the recovery of initial surfactant to 17% (Set 4). Over 30% of the initial surfactant was recovered for reuse with the Set 5 experiments.

The TOC of the wash effluent in FIGs. 27-30 increased with number of runs faster than the active matter, probably due to accumulation of oily soil.

### **Example V.**

Using the same process flow as used in Set 5, this experiment used a Unimac™ industrial washer. In order to simulate conditions at steady state, a minimum of six washes were made in which water was treated from one run, and then used in the subsequent run. In order to titrate the active matter, soap, and available chlorine, water samples were taken after performing the washes and the filtrations. In addition, TOC analyses were performed in the water samples. The reflectance of washed swatches was measured using a Hunterlab™ spectrophotometer. For all the washes, the dosage of detergent and bleach was 70% (66.5 ml) and 180 ml, respectively. FIG. 31 shows the soil removal on the test strips that was observed. The following Tables 20-21 show soil removal for the wash/filtration sequence.

**TABLE 20: Soil Removal for the Wash/filtration Sequence**

Wash	Red Wine	Raw, Unbleached	Immedial black	Blood, milk, Carbon black	Cocoa
1	81.32	26.24	69.87	77.89	71.19
2	86.18	26.98	73.09	73.39	63.69
3	83.60	23/73	71.12	73.77	63.33
4	83.16	28.04	75.94	74.97	60.39
5	85.85	29.02	74.65	70.53	56.23
6	83.49	29.47	76.88	73.58	56.91

**TABLE 21: Soil Removal for the Wash/filtration Sequence**

Wash	Blood	Carbon black, olive oil	Blood, milk, carbon black	Dust Sebum (Cotton 400)	Dust Sebum (PEDP)
1	81.50	37.21	77.15	66.33	84.40
2	79.09	41.29	74.07	68.55	89.31
3	75.62	34.58	73.89	71.66	89.23
4	80.65	45.65	74.87	69.15	88.49
5	75.61	47.49	63.15	65.51	87.54
6	74.88	40.09	74.59	62.89	85.95

The following table shows the TOC results for the wash/filtration sequence:

**TABLE 22: TOC Results for the Wash/filtration Sequence**

Wash #	Wash	Rinse (composite of 1,2,3)	Wash Retentate	Wash Permeate	Rinse Retentate	Rinse Permeate
1	545	43	634	278	56	39
2	549	71	862	383	115	50
3	830	87	1275	484	149	82
4	978	101	1195	522	146	104
5	973	128	1152	592	158	120
6	1051	141	-	-	-	-

- 5 During the wash/filtration sequence we studied the reflectance and brightness of redeposition swatches. These swatches were dried under different conditions. Some of them were dried with fabric softener, *see* FIG. 32, and some others were dried without fabric softener, *see* FIG. 33. These brightness of the redeposition swatches dried with and without fabric softener are shown in the following Tables 23 and 24.
- 10

**TABLE 23: Brightness of Redeposition Swatches Dried with Fabric Softener**

Wash #	Swatches 1,2	Swatches 3,4	Swatches 5,6	Swatches 7,8	Swatches 9,10	Swatches 11,12
Unwashed	87.27	86.99	86.08	87.42	86.58	87.02
1	85.98	-	-	-	-	-
2	85.70	86.02	-	-	-	-
3	85.95	85.18	85.47	-	-	-
4	86.70	86.00	86.00	86.42	-	-
5	86.55	86.76	86.79	86.88	86.91	-
6	86.22	86.02	86.14	86.50	85.91	85.77

**TABLE 24: Brightness of Redeposition Swatches Dried without Fabric Softener**

Wash #	Swatches 1,2	Swatches 3,4	Swatches 5,6	Swatches 7,8	Swatches 9,10	Swatches 11,12
Unwashed	84.82	85.66	85.31	86.05	86.15	85.88
1	86.20	-	-	-	-	-
2	86.15	86.63	-	-	-	-
3	86.92	86.82	86.68	-	-	-
4	86.90	86.78	86.74	86.90	-	-

Wash #	Swatches 1,2	Swatches 3,4	Swatches 5,6	Swatches 7,8	Swatches 9,10	Swatches 11,12
5	87.07	87.15	86.97	87.21	86.57	-
6	86.63	86.75	86.85	86.64	86.73	86.82

The active matter percentage for the wash/filtration sequence was as follows:

**TABLE 25: Active Matter Percentage for the Wash/Filtration Sequence**

Wash #	Wash	Rinse	Wash Retentate	Wash Permeate	Rinse Retentate	Rinse Permeate
1	0.0473	0.0044	0.0660	0.0246	0.0043	0.0039
2	0.0471	0.0073	0.0903	0.0309	0.0088	0.0055
3	0.0705	0.0098	0.1406	0.0362	0.0126	0.0078
4	0.0785	0.0104	0.1249	0.0372	0.0131	0.0095
5	0.0772	0.0109	0.1196	0.0404	0.0151	0.0106
6	0.0785	0.0158	-	-	-	-

5 The soap percentage for the wash/filtration sequence was as follows:

**TABLE 26: Soap Percentage for the Wash/Filtration Sequence**

Wash #	Wash	Rinse	Wash Retentate	Wash Permeate	Rinse Retentate	Rinse Permeate
1	0.00383	0.00042	0.00393	0.00167	0.00047	0.00017
2	0.00291	0.00048	0.00558	0.00166	0.00111	0.00038
3	0.00505	0.00060	0.00840	0.00238	0.00110	0.00060
4	0.00580	0.00085	0.00800	0.00285	0.00118	0.00076
5	0.00660	0.00099	0.00807	0.00278	0.00124	0.00061
6	0.00708	0.00128	-	-	-	-

The available chlorine for the wash/filtration sequence was as follows:

**TABLE 27: Available Chlorine for the Wash/Filtration Sequence**

Wash #	Wash	Rinse	Wash Retentate	Wash Permeate	Rinse Retentate	Rinse Permeate
1	0.02234	0.00203	0.00359	0.00406	0.00172	0.00141
2	0.01344	0.00156	0.00375	0.00438	0.00109	0.00141
3	0.01969	0.00203	0.00484	0.00641	0.00109	0.00156
4	0.02000	0.00188	0.00422	0.00547	0.00094	0.00109
5	0.02188	0.00156	0.00547	0.00688	0.00125	0.00141
6	0.0230	0.00188	-	-	-	-

10